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The spectra of certain class N stars

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SUBJECT: Part I. THE NATURE OF THE CLASS N SPECTRUM

Part II. VARIATIONS IN THE SPECTRA OF CLASS N VARIABLES

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Part I. The Nature of the Class N Spectrum

Introduction

Stellar spectra which are relatively faint in the more refrangible region and which are characterized by an absorption band extending from 4740A to about 4650A are designated in the Draper Classification as Class N spectra. When examined with high dispersion, these spectra are found to contain great numbers of absorption lines, as well as hundreds of apparent bright lines. No other stellar spectra show so many bright lines. In appearance, the stars of Class N are distinguished by their orange or ruddy color, due to their relative weakness in the blue and violet light. They are the reddest stars known, not infrequently having color indices as large as four.

The Class N stars form a branch in the main spectral sequence, being most closely related to the Class K stars through Class R. They seem to terminate the branch, for no spectra which can be considered a continuation beyond the Class N stage have yet been discovered. This fact, combined with their ruddy color, suggests that the Class N stars are relatively cool and have nearly reached the point of final extinction. We seem to be dealing with the coolest stars accessible to direct observation. It follows, therefore, that their study is of particular importance in determining the course of stellar evolution.

The purposes of the present investigation are:

(1) To determine the chemical elements present in the Class N stars.

(2) To study the relation of the lines identified with those of the various temperature classes, and with enhanced, sun-spot and α Orionis lines.

(3) To obtain evidence bearing on the character of the apparent emission lines.

(4) To make a study of the absorption bands in these stars.

(5) To investigate the relation of the Class N and Class R spectra.

(6) To correlate the observational material in a general conclusion as to the probable physical condition in these stars.

Previous investigations

Class N of the Draper Classification is identical with Secchi's Fourth Type. Secchi was the first to study the spectra of stars of this type, and although only a few were bright enough for him to observe, he measured the positions of their characteristic bands and identified them with bands produced by carbon. His measures were rather inaccurate, but his conclusion regarding the origin of the bands has been amply confirmed by subsequent observers. Visual observations by Duner[1] and Vogel and photographic observations by Hale, Ellerman and Parkhurst[2] have left no doubt that the absorption bands refered to belong to the Swan spectrum of carbon.

Astronomers have held different opinions regarding the presence of the emission lines in the spectra of the Class N stars. Vogel[3] and Lockyer[4], observing visually, were unable to detect any bright[5] lines. Duner[6], Keeler and Campbell saw them quite distinctly and they are a prominent feature of the spectrograms obtained by Hale, Ellerman and Parkhurst.[7] The latter observers concluded that the bright lines on their spectrograms were due to emission, and they presented a number of strong arguments in support of this view. Among other evidence which they obtained may be mentioned the sharpness of the lines and the fact that the absence of a number of iron lines from the absorption spectrum could readily be accounted for on the assumption of overlying bright lines. They were unable to identify any of the bright lines except the hydrogen line Hβ which appears in a few of the stars. They noted that in the spectrum of 280 Schjellerup, Hβ undergoes variations in brightness.

The work of Hale,Ellerman and Parkhurst[8] is by far the most complete and comprehensive study of the Class N stars that has been made. Theyw were , unfortunately, not able to investigate the less refrangible portions of the spectrum satisfactorily, because effective methods for rendering photographic plates sensitive to the longer light waves had not been developed at that time. In addition to their study of the bright lines, they investigated the absorption spectra of the Class N stars and identified a large number of the absorption lines with lines of known substances; notably,hydrogen,vanadium,magnesium,sodium, iron,chromium,titanium,nickel and manganese. Their measures confirmed the presence of carbon,both in the state corresponding to the Swan spectrum and in combination with nitrogen to form cyanogen. Although the correspondence with sun-spot spectra was not exact, it was found that many lines widened in sunspots, are prominent in the Class N stars. A close resemblance between the spectra of Classes M and M was noted,and from this the authors concluded that the two types of stars should be "classed together as coordinate branches leading back to the sun."

Quite recently Dr. Rufus[9] has proved the existance of a spectral sequence leading from the stars of the solar type through the Class R stars to Class N.

Apparatus

Several spectrographs were used in this investigation. They are briefly described below and will hereafter be refered to by number.

1.A 3-prism instrument set for minimum deviation at D.Camera 16-inch; D central; linear dispersion (r) at D = 40A per mm. Plates measurable from 5500A to 6550A.

2.Spectrograph 1 with H_α set central on the plate. r at H_α = 64A per mm. Plates measurable from6950A to 6450A.

3. Spectrograph 1 with a 32-inch camera substituted for the 16-inch.
   D central; r at D = 20A per mm.
4. A 3-prism instrument set for minimum deviation at H_β. Camera 16-inch;
   H_β central; r at H_β = 20A per mm. Plates measurable from 4500A to 5000A.
5. A 1-prism instrument set for minimum deviation at D. Camera 16oinch;
   D central; r at D = 120A per mm.
6. Spectrograph 5 with a 6-inch camera substituted for the 16-inch.
7. The large quartz spectrograph describedby Mr. Wright in Lick Obs. Bul.,
   No 291. Used in its slitless adaptation.

Spectrograph 7 was used in connection with the Crossley reflector. The others were attached to the 36-inch refractor.

Seed 30 plates were used for the exposures made with spectrographs 4 and 7. All the other exposures were made on Seed plates sensitized by means of Wallace's three dye formula. For this purpose 27's were used in 1917 and 23's after that time. It was my experience that the bathed S23 plates were at least as fast as the 27's, possessed a much finer grain, and were not so liable to chemical fog. For a few of the later plates homocol was omitted from the sensitizing formula. This resulted in a slight general increase in speed without appreciably altering the relative sensitivity of the plates to the different portions of the spectrum.

Observations

The brightest two Class N stars in the northern hemisphere, 152 Schjellerup and 19 Piscium, were selected for detailed study. It was decided to limit the investigation to those portions of the spectrum included between 4700A and 4980A. in the photographic region and between 5500A and 6950A in the visual region.

In the photographic region of the spectrum the most conspicuous feature is the carbon absorption band beginning at 4738A and gradually fading out toward the violet. On the plates of 19 Piscium several of the secondary heads of the absorption bands are visible, but in 152 Schjellerup the general absorption is so great that they are entirely blotted out. The continuous spectrum in the photographic region of both stars is interrupted by a great number of absorption lines and appears to be overlain in places by numerous bright lines.

A striking feature in the visual region, also, is the profusion of absorption lines, about three-hundred having been measured. In addition to the absorption lines, there is about an equal number of apparent bright lines. The result is that many parts of the spectrum present an appearance of alternate bright and dark lines crowded so closely together that the continuous spectrum is either invisible or is only seen through occasional spaces between the absorption lines. These effects introduce considerable uncertainty in the proper choice of lines for measurment and in the correct interpretation of the real nature of the lines. There is no question, however, as to the reality of the stronger absorption lines, especially since many have been identified with known substances. The absorption spectra of the two stars in the visual region differ in many details. In 152 Schjellerup, beginning at 5500A and proceeding toward the red, the spectrum is blank with the exception of a few bright lines until the head of the carbon absorption band at 5635A is reached, when the continuous spectrum abruptly becomes visible and can be followed as far into the red as the plates retain appreciable sensitivity; i.e., to about 6950A. In 19 Piscium the absorption to the violet of 5635A is less complete. Several of the heads of the Swan spectrum are here visible, while in 152 Schjellerup the spectrum is almost entirely blotted out by the absorption. Figs.   illustrate the general character of the spectrum.

The plates selected for measurment were secured with spectrographs 1,2 and 4. The wave-lengths, character, intensities and identifications of the lines recorded on the spectrograms are given in Table III. The wave-lengths of the lines in both stars depend upon measures of at least two plates in each potion of the spectrum except in the case of 19 Piscium between the wave-lengths 6550A and 6950A, where only one plate was available. Unfortunately the wave-lengths derived from this plate show a systematic error of +0.3A, due probably to some instrumental defect.

A spectrogram of Orionis (Class Ma) was obtained with spectrograph 3 for purposes of comparison with Class N spectra. It was underexposed but measurable throughout most of the region from5660A to 6500A. The wave-lengths derived from measures of this plate are given in Table IV.On account of the underexposure of the spectrogram the list is not complete, but it contains a sufficient number of lines to make it useful for a comparative study of the two types of stars.

Identification of the Absorption Lines.

The identification of the absorption lines presents a number of difficulties. When there are a great many lines, it is possible to find a large number of accidental coincidences with lines of known substances. Unless proper precautions are observed this is apt to lead to erroneous identifications.Furthermore, if the apparent bright lines are actually due to gaseous emission, they will in many cases serve to conceal absorption lines which we should otherwise expect to see. In this investigation the following method of identification has been adopted.

It was decided that from 4700A to 4950A, a difference of 0.2A or less between a laboratory wave-length and a wave-length as measured in the star

should constitute as coincidence. From 5500A to 6000A, the limit was 0.3A, from 6000A to 6400A,0.4A, and from 6400A to 6950A, 0.5A. These limits were determined from a careful study of the agreements between wave-lengths measured in the two stars. Having defined exactly what was meant by a coincidence, it became possible to compute the proportion of the lines of any substance for which we should obtain accidental coincidences with lines in the Class N stars. The excess of coincidences over the number attributable to chance was regarded as measuring the probability of an element's occurrence in the stars. When this criterion indicated the probable presence of an element, the coincidences obtained were further examined in order to determine whether they occurred principally among one class of lines such as low temperature, enhanced or sun-spot lines. If this was found to be the case, the presence of the element was thereby further substantiated.

In the course of this investigation the following elements have been identified; carbon,hydrogen,iron,titanium, vanadium, chromium,sodium,manganese, calcium,scandium and yttrium. All but the last two were identified by Hale, Ellerman and Parkhurst. They observed lines of nickel and ~~manganese~~ magnesium in the Class N stars, but on my plates the evidence for nickel is very slight, and there is no indication of the presence of magnesium. The latter,however, is to be expected since no prominent magnesium lines fall within the regoin covered by the spectrograms studied in this investigation. In addition to the above elements,lanthanum,barium,cadmium and zirconium are probably present.

The details of the identifications are given below.

Hydrogen. No hydrogen lines were observed in 152 Schjellerup or in 19 Piscium,but a number of plates of other Class N stars,taken with spectrographs 5, 6 and 7, recorded bright hydrogen lines. These plates will be described

in Part II. Hale, Ellerman and Parkhurst found H and H as absorption lines in 19 Piscium.

Iron. The enhanced lines of iron do not appear in these stars, but the low temperature lines are prominent. Table I illustrates this.

Table I

			Coincidences		
Temp. Class	No. of Lines.	Average Int.	152 Schj.	19 Pisc.	Accidental
V	10	10.3	3	3	1.4
IV	6	10.5	1	1	0.9
III	25	10.5	8	9	3.6
II and IA	4	12.5	2	2	0.6

The first column contains King's[10] temperature classes. The lines appearing at the lowest temperatures comprise Class I. In the second column is given the number of lines in each Class. In Temperature Classes V and IV only the lines recorded by King as 8 or brighter have been included. The purpose of this was to make the average intensity in the arc for Class V and IV equal to that for Class III. Column three contains the average intensities of the lines considered in each class. In the fourth and fifth columns are tabulated the numbers of coincidences with 152 Schjellerup and 19 Piscium respectively, and in the sixth column are given the number of accidental coincidences we should expect in each star. There is evidently a tendency for the coincidences to occur among the low temperature lines.

Titanium and Vanadium. With the exception of carbon, these elements are the most prominent in the Class N stars. In the case of each element over half of the strongest fifty arc lines to the violet of 6400A are represented by absorption lines. It is impossible to make a satisfactory comparison of the star lines with King's[11] temperature classes, because in the region of the spectrum studied, the high temperature lines of these elements are nearly all quite faint in the arc. The enhanced lines, however, are not present among the star lines.

Chromium. The strongest chromium lines do not occur in the portions of the spectrum studied in this investigation, but there are enough coincidences with the lines available to identify definitely chromium in these stars. Between 4700A and 4980A practically all the strongest arc lines of chromium are represented by absorption lines, but in the visual region, the correspondence is not so satisfactory, several of the stronger chromium lines apparently being concealed by overlying bright lines. As in the case of titanium and vanadium, the material is not suitable for a comparison with King's[12] temperature classes. The ten enhanced lines in the photographic region, as given by Lockyer[13], do not appear in these stars.

Sodium. In addition to the D lines, there are three other prominent lines of sodium present. The D lines are very broad and heavy, being about 3 A wide in 152 Schjellerup and 4A wide in 19 Piscium. In no other spectral tpye do the sodium lines have nearly the intensity shown in the Class N stars. In one star, R CYgni, Mr. Wright[14] observed greatly broadened sodium lines. This star, however, does not correspond exactly with any particular spectral class, but resembles more than any other the Class Md stars.

Manganese. Of the seven strongest arc lines of manganese in the region 4740A to 4980A, four are represented in the Class N stars and two of the remaining three are accounted for by blends. In the visual region there are three out of a possible six coincidences, the unrepresented lines being, however, the three strong magnesium lines at 6022A, 6012A and 6013A.

Calcium. Hale, Ellermen and Parkhurst were able, by giving a very long exposure, to photograph the H and K lines and the line at 4227A in 19 Piscium. They interpreted the great intensity if 4227A as indicating a low temperature in the star. I made an attempt th photograph the H and K lines in the spectrum on the Class N star 132 Schjellerup, (U Hydrae), using for the purpose, spec-

tograph 7. Although the exposure was thirty times as long as was necessary to obtain the region about Hβ, it was not long enough to show the spectrum in the neighborhood of H and K. The line 4227A appears much broadened on the plate. The calcium lines are not prominent in those portions of the spectrum of 152 Schjellerup and 19 Piscium studied with high dispersion.

Scandium. The presence of scandium in the Class N stars is well established. Of the ten strongest scandium lines given by Fowler[15], there are coincidences for seven in 19 Piscium and an eighth is represented by an absorption line which falls just outside the coincidence limits. In 152 Schjellerup there are four coincidences. The prominent scandium lines at 474410A, 4415.7A and 4400.6A, are all represented among the absorption lines measured by Hale, Ellerman and Parkhurst. The prominent ehhanced lines at 5658A and 5684A are not found in these stars.

Yttrium. Of the eight strongest lines between 4740A and 4890A, four are represented in 19 Piscium and three of the remaining four are accounted for by absorption lines falling just outside the coincidence limits. Five out of the ten lines in the photographic region not included in my measures are coincident with absorption lines measured by Hale, Ellerman and Parkhurst. The remaining lines are all accounted for by blends, the presence of carbon absorption bands or apparently overlying bright lines. In the visual region there is only one coincidence out of a possible four. Some of the enhanced lines of yttrium coincide with the absorption lines. The lines at 4398A, 4423A and 4900A are examples of this.

Lanthanum. The number of coincidences with absorption lines in the stars renders the identification of lanthanum quite probable. Of the thirty-eight lines given as 5 or brighter in Kayser's table of "Hauptlinien"[16], there are nine

coincidences with absorption lines in 152 Schjellerup and twelve in 19 Piscium. In the photographic region there is a similar excess of coincidences over the number attributable to chance. There is no material available for a comparison of enhanced lines, but the two chromospheric lines at 4740A and 4743A are missing from the spectra of the stars.

Barium. This element has not been positively identified in the Class N stars, but it is probably represented by a few absorption lines. Watt's "Index of Spectra", Appendix V, gives twenty-one barium lines, 6 or brighter, in the portions of the dpectrum under consideration. Five of these are represented by absorption lines in 152 Schjellerup and six in 19 Piscium. The number attributable to chance is three in each star. It should be noted that many of the stronger barium lines are comparatively weak in the solar spectrum, and that those two at 5853A and 6141A, which are strong in the sun, are represented by absorption lines in 19 Piscium.

Cadmium. There are not many lines in the cadmium spectrum, but of the eight strongest, five coincide with absorption lines in 19 Piscium. The two most prominent cadmium lines, however, at 6523A and 6438A, are not represented in either stars, but one of them is apparenly covered by a bright line in 152 Schjellerup.

Zirconium. In the photographic region four-tenths of the strongest zirconium lines are represented by absorption lines in each of the stars, while in the visual region the percentage is three-twenty-fotrths for 152 Schjellerup and eight tenty-fourths in 19 Piscium. In both cases the percentage becomes larger when we exclude the fainter lines.

The prominence of the three rare earth metals, scandium, yttrium and lanthanum, in the Class N stars is rather surprising when we consider their scarcity on the earth. All three, however, are fairly prominent in the sun, and scandium, in addition to having many lines widened in sunspots, has been identified in a

number of stars by Lockyer[17]. It should be noted that these three elements are the rame earth metals of the boron group.

Comparison eith Sun-spots and αOrionis.

While there are many similarities between the Class N spectra and the spectra of sun-spots, a number of notable differences exist. The strongest argument in favor of a connection between the two types of spectra is the prominence intthe Class N stars of the conspicuous sunspot elements. The seven elements,Ca,Na, V,Sc,Cr,Mn, which according to Adams[18] have over fifty percent of their solar lines strengthened in sun-spots,are all represented in the Class N stars. In the case of titanium and vanadium, there is some evidence that the sun-spot lines are those which appear prominently in the stars.

A considerable number of very prominent sun-spot lines are missing fromm the Class N stars. Examples of this are afforded by six lines of titanium which Adams gives as greatly strengthened in sunspots. Only two of the lines are represented in 152 Schjellerup and one in 19 Piscium. The fact that the three manganese lines at 6022A, 6017A and 6013A do not appear in the Class N stars has already been discussed. According to mitchell[19] these three lines are strengthened in sun-spots.

An inspection of Table IV shows a close relationship between αOrionis and the Class N stars. There are fifty two coincidences among one humdred and twenty seven αOrionis lines, and most of the remaining sevehty five can be accounted for by blends or apparently overlying bright lines in the Class N stars.

The Bright Lines

No single test which establishes definitely the character of the bright lines has been found, but there is evidence from which we can draw fairly reliable conclusions.

There are three principal arguments against the theory that the bright lines are due to gaseous emission.

(1) None of the bright lines, except those due to hydrogen, have been identified with lines of known substances.

(2) It is well known that spectrograms of Class M stars often show details which at first sight appear to be bright lines, but which are merely short sections of continuous spectrum between absorption lines. This suggests a similar explanation for the appearance of the bright lines in the Class N stars. In measuring the plates it was frequently difficult to decide whether to measure two dark lines or the narrow bright line between them, and for this reason many of the bright fainter lines measured may be merely portions of the continuous background.

(3) If the bright lines are merely portions of the continuous spectrum between absorption lines, they would naturally tend to avoid the positions of lines of elements known to produce absorption in the stars. In identifying the absorption lines, it was found that in nearly every case, when we consider an element known to exist in the Class N stars, the number of coincidences of the lines of that element with bright lines in the stars' spectra is considerably less than would be required by a random distribution of the bright star lines. This is best illustrated by a comparison of the spectra of the Class N stars studied, with the spectra of α Orionis. It has already been shown that the absorption spectra are similar in the two types of stars. A chance distribution of the bright lines in the Class N stars would require that there be about thirty coincidences with α Orionis lines. There are only sixteen. This is about what we should expect if the bright lines were not due to emission.

There is considerable evidence that the bright lines are due to gaseous emission. The following arguments lend support to this view.

(1) Nearly all the bright lines are as sharp and narrow as the comparison lines. Those few which are broadened are easily explainable as blends. In fact the earlier spectrograms, which were taken on coarser grained plates than the later ones, often showed broadened bright lines, which on the finer grained plates, were seen to be double or even triple.

(2) A large number of the bright lines are of great intensity, being much brighter than any of the apparent bright lines seen in the Class M stars. We should expect that if they were merely short sections of continuous spectrum between absorption lines, they would be relatively more prominent the stronger the absorption. In the visual region the Class N stars appear to suffer less selective absorption than do the Class M stars in the region of shorter wave-length, yet most of the bright lines in the visual region of the Class N stars are much more prominent than any apparent bright lines in the stars of Class M. When we consider the Class N stars alone, the bright lines in the visual region are more prominent than those of shorter wave-length, althoughtthe photographic portion of the spectrum of the spectrum possesses stronger and more numerous absorption lines.

(3) Certain strong bright lines present on the plates of 152 Schjellerup are very faint or absent on the 19 Piscium spectrograms.and vice versa; yet in nearly all such cases the wave-lengths of the lines measured in both stars agree within observational error. The few exceptions can be attributed to the fact that the lines in the two stars are actually different. In view of the marked differences between the absorption spectraof the two stars we should not expect such close agreemant in the wave-lengths of the bright lines, if they were merely short sections of continuous spectrum bounded by absorption lines.

(4) The behavior of some of the bright lines with reference to certain

absorption lines is significant in this regard. Some of the absorption lines are very broad and hazy at the edges. The D lines of sodium are good examples of this. In some cases, however, a broad heavy absorption line fades out gradually on one side and on the other is limited sharply, apparently by a bright line. This would hardly be possible if the apparent bright line~~s~~ were merely a portion of the continuous spectrum, because we know of no condition which causes an absorption line to broaden and become hazy on one side while it remains perfectly sharp on the other. The lines 5745A and 6162A in 19 Piscium are examples of unsymetrically broad absorption lines. They are easily seen in figure .

(5) If we can be certain that a particular absorption line should be prominent in the spectrum of one of the Class N stars and if in the place of that line we find a bright line, there will be no doubt that the bright line is due to gaseous emission. Unfortunately this test cannot be applied rigorously because we cannot certainly predict the presence of any absorption lines except the D lines of sodium. Here the test gives only negative results. There are, however, a number of cases of bright lines where we should reasonably expect absorption lines. Table II contains a list of the more important examples of this.

(Insert Table)

The first and second columns require no explanation. Columns three and four contain King's arc intensities and temperature classes respectively. The solar intensities are given in column five, while column six contains the amount of strengthening in sun-spots according to Mitchell. In columns seven and eight are tabulated the intensities in 152 Schjellerup and 19 Piscium of bright lines having practically the same wave-lengths as those

Wave Length I.A.	Identification	Int. arc	Temp. Class	Int. Sun.	Int. Spot	152 Schj	19 Pisc	Remarks.
5662.21	Ti	12	III	0	4	(2 Bh)	1B	
5668.39	V	12	II	000	6	3 B	1B	Int. 6 in α Orionis according to Hale and Adams[20]
5701.56	Fe	7	III ?	4		2B	(1B)	Int 1 d?. in α Orionis
5783.12 5783.92	Cr Cr	20 20	III III	2 3	7 5	}	2B	
5787.95	Cr	40	III	4		6B	2B	Int 5 in sun-spots according to Hale, Adams and Gale
5790.96	Cr	50	III	4		(1B)		Int 2 in α Orionis
6085.24	Ti	20	II	2	6	(3 B)	(1B)	Blend with Fe in ☉
6219.29	Fe	6	III	6	5	2B	2B	
6251.81 6252.56	V Fe	30 20	I III	00 7	7	} 2B	(1B)	
6258.71	Ti	50	II	3	5	(1B)		
6285.17	V	20	I	00	7	2B		
6330.11	Cr	25	IA.	1	9	(8 Bh)	(7 Bd)	Int 1 d? in α Orionis.

given in the first column. A parenthesis indicates that the line falls outside the coincidence limits but is sufficiently close to include tho wavelength in column one within its actual width on the plate as determined by the slit width and photographic spreading.

The vanadium line at 5668.39A should be noted in particular. It could not be measured on the plate of α Orionis because the plate was greatly underexposed in this region, but it was measured by Hale, Adams and Gale who assigned it an intensity 6 on their scale.

(6) Observations of certain variable stars of spectral Class N are described in ~~another paper~~ Part II. On account of the faintness of the stars studied it was necessary to use very low dispersion; accordingly only a few of the stronger bright lines were visible on the spectrograms. In two or three of the stars there is evidence that some of the bright lines vary in intensity. One line in U Cggni and RS Cygni at 5845.3A showed marked variations. This can only be interpreted on the supposition that we are dealing with an emission line.

(7) The absence of large numbers of absorption lines which we should expect to find in the spectra of the Class N stars is easily explained if we consider the bright lines to be due to emission. A weak emission line falling within the limits of an absorption line might serve to conceal the latter, and at the smae time the emission line, not being reinforced by the continuous spectrum, would be so reduced in intensity as to escape notice. This can explain the relatively few bright lines where we should expect to find absorption lines.

(8) The lack of identification for the bright lines is not easy to explain but it should be remembered that there a number of bright lines in the Class Md stars which have not been identified. Nearly all these lines are in the more refrangible region of the spectrum, and therefore it is impossible to make a comparison with the lines in the Class N stars. It was thought

that there might be some bright lines in the visual region of the Class Md stars which would coincide with those of Class N. Accordingly some spectrograms of o Ceti (Class Md) were obtained with spectrograph 1 while the star was near maximum light. The Hα line of hydrogen was the only bright line recorded and for this reason no comparison was possible.

In general the evidence at hand, while not conclusive, indicates strongly that the bright lines are actually emission lines and are not sections of continuous spectrum between absorption lines.

The fact that the bright lines probably serve to conceal certain absorption lines indicates that they originate at higher levels in the stellar atmospheres then do the absorption lines. On the other hand, a reference to figure shows that in the region of carbon absorption to the violetof 5636A, the bright lines are greatly decreased in number and intensity. The obvious explanation is that the carbon absorption occurs at a higher level than that in which the bright lines have their origin.

The Absorption Bands

The absorption bands due to the Swan spectrum of carbon are the most characteristic feature of the Class N spectrum. The groups beginning at 5635A, 5165A and 4737A are always very prominent, while the group at 4382A appears on the plates of Hale, Ellerman and Parkhurst, but it is not so strong as the others. The three heads of the first group at 6191A, 6122A and 6060A are represented in the Class N stars by what appear to be broad and hazy absorption lines. This group is relatively inconspicuous in those stars but in view of its faintness in laboratory sources, this is to be expected.

A rather remarkable feature is associated with the carbon group beginning

at 4737A. In 19 Piscium there is an apparent head at 4745A and in 152 Schjellerup one at 4752A. The latter band extends beyond 4737A and practically conceals the spectrum covered by it. On certain strongly exposed plates of 152 Schjellerup obtained by Dr. Moore for radial velocity, the heads at 4737A and 4745A are visible though quite faint. The measured wave-lengths of the three heads are 4737.80A, 4745.15A and 4752.76A. The first belongs to the Swan spectrum, but the others are not identified. If, however, we take the differences in wave-length btween the first and the second and the second and the third, we obtain the values 7.35A and 7.61A respectively. These differences are constant within the errors of measurment, suggesting a common origin for the three bands.

The absorption bands due to cyanogen are also prominent in the Class N stars. Hale, Ellerman and Parkhurst observed a decrease in the intensity of the cyanogen bands of group II(beginning at 4606A and extending to about 4500A) with greater development of the Class N characteristics. Rufus has observed that these cyanogen bands are stronger in the Class N stars than in those of Class R. These observations indicate that the maximum intensity in the cyanogen bands occurs among the early Class N stars. The present investigtion throws little light on the matter bacause the high dispersion plates do not include these bands. However, an observation of the third cyanogen group beginning at 4216A is of interest. This group is very prominent in the Class R stars as shown by Dr. Rufus's spectrograms and by a plate of the Class R star B.D. +42°2811 which I secured with spectrograph 7. It does not appear in the spectrum of 19 Piscium as photographed by Hale, Ellerman and Parkhurst, nor on the plate of 132 Schjellerup (ClassN) obtained with spectrograph 7. It is quite probable that this group is absent or very weak in the other Class N stars. A study of the behavior of the

different cyanogen groups might lead to a better understanding of the physical conditions in the stars of Classes R and N.

No other bands have been certainly detected in the Class N stars. In the spectrum of 19 Piscium a number of apparent bands with heads toward the violet were measured, but their character is very uncertain. The wave-lengths are 6789A, 6807A, 6826A, 6865A, 6892A and 6909A. They could not be identified with any known bands.

Relation Between the Stars of Classes R and N

By a study of the photographic region of the Class R stars, Dr. Rufus has eastblished their intermediate character between the stars of Classes G and N. In order to extend these results to the visual region, a spectrogram of the Class R star B.D.-10°5057 was secured with spectrograph 5. The spectrum appears to be in most respects that of an underdeveloped Class N star. The groups of carbon bands beginning at 5635A, 5165A and 4737A are not nearly so prominent as in the Class N stars, and the bright lines are missing or very weak. The carbon bands of the first group, however, seem to be equal in strength with those in the Class N stars and instead of being reduced to hazy lines they extend considerable distances toward the violet.

The spectra of two Class R stars, B.D.-10)5057 and B.D.+42°2811, were photographed with spectrograph 7. Three very strong absorption bands with heads at 4210A, 3885A and 3592A were recorded. Owing to the lack of a comparison spectrum, these wave-lengths are subject to condiderable uncertainty, but they are sufficiently accurate ~~takt~~ that they serve to identify the bands with the cyanogen groups having heads at 4216A, 3883A and 3590A. The group at 4216A was measured in the Class R stars by Dr. Rufus and ascribed to cyanogen, but the others have not been heretofore observed to my knowledge.

The H and K lines and the 4227A line of calcium as recorded on these spectrograms are of about the same intensities as in the Class G stars. The intensity of 4227A is very much less than in the Class N stars, 19 Piscium and 132 Schjellerup, while the H and K lines are as least as strong as in 19 Piscium. In view of the well known behavior of theseelines with different temperatures, this is additional evidence of low temperatures in the Class N stars.

Conclusions

The material of the present investigation enables us to draw a number of conclusions as to the physical conditions existing in the Class N stars, such as temperature, vapor density and relative level of the various constitutents in their atmospheres.

The evidence indicates a comparatively low temperature in the Class N stars. They are characteristically faint in the shorter wave-lengths; all the enhanced lines are absent; the low temperature line of calcium at 4227A is relatively strong. Probably the most significant evidence is that contained in Table I. Since, for the lines of equal arc intensities, we find a larger proportion of coincidences among the low temperature than among the high temperature lines, we infer that the temperature in the stars' atmosphere is somewhat lower than tahn in the arc, possibly 3000°C. Unfortunately, this estimate is subject to a number of uncertainties. The amount of observational material used is small; other conditions than temperature may affect high and low temperature lines differently; the experimental ~~adta~~ data refer to emission lines while in the stars we are dealing with absorption lines. With these limitations in mind, we may consider tha above estimate of temperature as provisional. It applies, of course, only to the reversing layer of the Class N stars. We can make no estimate of the temperature in their photospheres. The differences between the spectra of the

Class N stars and those of sun-spots and Class M stars may be, in a large measure, due to the low temperature conditions existing in the former.

The temperature in the Class N stars in undaubtedly low enough to permit the existence of many compounds, whose presence we might detect by means of their absorption spectra. Cyanogen is known to exist in these stars and possibly carbon monoxide also. Rufus has explained the absence of titanium oxide by referring to Baly's observation that a slight excess of oxygen destroys the Swan spectrum.It is not unlikely that there is enough carbon in the Class N stars to combine with all the oxygen to form carbon monoxide. Under these circumstances, we shpuld not expect to observe the spectra of any oxides other than carbon monoxide. The appearance of several portions of the Class N spectra in the visual region, especially near 6250A, suggests a banded structure, but I have not been able to make any identifications with known band spectra.

The strong gaseous absorption in the Class N stars indicates a very heavy reversing layer, and the width of such lines as the D lines of sodium is evidence of considerable vapor density. The great amount of absorption by gases in the reversing layer, however, does not seem sufficient to explain the faintness of these stars in the shorter waves. The absorption lines in 152 Schjellerup are neither stronger nor more numerous than those in 19 Piscium, yet the spectrum of the latter extends much farther into the violet than that of 152 Schjellerup. Dr. Merrill[21] has suggested that the variation in the Class Md stars may be produced by the alternate condensation and vaporization of the outer potions of their gaseous envelopes. In the Class N stars the dense atmospheres and comparatively low temperatures would be favorable conditions for the formations of ~~similer~~ clouds of solid and liquid particles at high levels. If these particles were of the same average size as those constituting blue smoke and were sufficiently numerous , ~~tehy~~ they would produce nearly complete absorption of the shorter

waves without affecting the less refrangible portions of the spectrum to such a large extent. While this hypothesis has not much foundation in experiment, it is apparently not at varianve with the observed phonomena.

The relative levels of the elements in the Class N stars are best evinced by the behavior of the bright lines. As previously indicated, the bright lines have their origin above most of the substances producing absorption lines. The carbon absorption however, seems to be very effective in cutting down the intensities of the bright lines, from which we infer that it exists at very high levels in the stellar atmospheres. The outer portions of the carbon envelope may condense to form the clouds refered to above.

This discussion enables us to picture the probable physical aspect of a Class N star. Above the heavy and cool reversing layer are the substances producing the bright lines, and surrounding the whole is an atmosphere composed in part, at least, of carbon vapor. It is possible that the outer portion of this atmosphere condenses to form occulting clouds whose selective absorption in the shorter wave-lengths is largely responsible for the characteristic ruddy color of the star. With further condensation of this outer atmosphere through loss of heat by radiation, the absorption will conceivably increase until the star reaches final extinction.

Summary

The spectra of two of the brightest Class N stars, 152 Schjellerup and 19 Piscium, have been studied with high dispersion in order to obtain evidence of the physical conditions existing in their atmospheres.

(1) The following elements have been identified in these stars: carbon, hydrogen, iron, titanium, vanadium, chromium, sodium, manganese, calcium, scandium and yttrium. The presence of lanthanum, barium, cadmium and zirconium is

probable.

(2) The low temperature lines of the elements are prominent in the Class N stars.

(3)There are a number of similarities between the Class N spectra and the spectra of sun-spots and Class M stars.

(4) Evidence bearing od the reality of the bright lines indicates that they are due to gaseous emission. None of them except the hydrogen lines have been identified.

(5)The absorption bands in the Class N stars have been studied. The first cabbon group of the Swan spectrum is represented by three narrow absorption bands, while the other four groups are very prominent. The cyanogen group at 4216A is more prominent in the Class R stars than in those of Class N, while according to the observations of Rufus the cyanogen group beginning at 4606A is stronger in the Class N stars.

(6) Certain conclusions as to the probable physical conditions in the Class N stars are derived from the observations.

Footnotes

1. Kongl. Svenska Vetenskaps Akad.,21,No.2,1884.
2. Publ. Yerkes Obs.,2,253,1904.
3. Publ. der Astroph. Obs.zu Potsdam,4,Part 1,23,1885.
4. Proc. Roy. Soc.,66,126,1899.
5. For simplicity, apparent bright lines will hereafter be refered to as "bright lines", the term "emission lines ", being reserved for lines known to be due to gaseous emission.
6. Ap. Jour.,9,121,1899.
7. Publ. yerkes Obs.,2,253,1904.
8. Ibid.
9. Publ. Detroit Obs.,2,103,1916.
10. Contributions Mt.Wilson Obs.,3,309,1912.
11. Ibid.,4,233,1913. 5,167,1914.
12. Ibid.,5,167,1914.
13. "Tables of Wave-lengths of Enhanced Lines," Publ. Solar Physics Committee,
14. Mon.Not.R.A.S.,72,548,1912.
15. Phil. Trans.,A,209,47,1908.
16. Handbuch der Spectroscopie,6,931,1912.
17. Proc. Roy. Soc.,74,538,1905.
18. Contributions Mt. Wilson Obs.,2,111,1909.
19. Ap.Jour.,22,4,1905.
20. Contributions Mt. Wilson Obs., 1,117,1906.
21. Publ. Detroit Obs.,2,45,1916.

Explanation of Tables III and IV

Heads of absorption bands are indicated by the letter H.
Bright and dark lines are indicated by the letters B and D respecti
A line which is broadened is marked b; one which appears doubl
is marked d; and one which appears hazy is marked h
An interrogation ~~point~~ mark indicates that the character of the line
is open to considerable doubt.
Where the symbol for an element is placed in parentheses,
it is to be understood that the agreement in wave lengths
is not within the coincidence limits as defined on
pages 6 and 7.

Table III

152 Schjellerup and 19 Piscium

λ 152 Schj.	Int	λ 19 Pisc.	Int	Identification
		4697.75	H	C
		4716.52	H	C
		37.80	H	C
		38.94	2B	
		39.62	2D	Zr
		42.04	1D	
		44.54	2D?	
		45.15	H	
		46.54	4B	
		47.31	3D	
		48.24	3B	
		49.55	2D	
		50.44	2B	
4752.76	H			
53.38	1D	53.22	1D	Sc
54.29	1D			Mn
55.11	2B? b	55.14	3B b	
55.80	2D	56.02	2D	Cr
56.96	2B?	56.92	3B b	
57.80	2D	57.98	2D	Ti (V)
59.18	2D	59.16	2D	Ti
		59.74	1B	
60.67	2B	60.40	2B	
61.00	1D	61.16	2D	Y
		61.99	2B? b	
63.21		62.81	1D	
63.21	2B	63.28	1B	
63.68	1D	63.85	1D	
65.27	1B			
65.82	1D			Mn
66.74	1D	66.77	3D	V (Mn) La
68.34	2D			Fe
69.14	1B?	69.09	1B?	
		69.86	1D	
70.63	1B?	70.51	2B?	
71.22	1D	71.17	1D	Ti
72.46	1D	72.64	1D	Zr
74.87	3B	74.62	1B?	
		77.30	1B?	
78.03	2B?			
		78.05	1D?	(Ti)
78.73	1D?			
79.44	1D	79.61	1D	Sc
79.80	1B			
80.14	1D?			
81.23	2B?	81.17	1B?	
81.81	2D	81.83	2D	Ti
82.37	2B			
83.53	1D	83.46	1D	Mn
84.74	1D	84.77	3D	Zr
		85.65	2B	
86.66	2D	86.55	2D	V Y
87.82	1D			
89.55	3D b	89.38	5D b	Fe Cr
		90.63	2B? d	
90.90	1B			
91.42	1D?	91.50	1D	
92.04	2B?			
92.62	2D	92.57	1D	Ti Cr
93.46	1B?	93.80	1B?	

λ 152 Schj.	Int.	λ 19 Pisc.	Int.	Identification
4794.79	2B			
95.72	2B	4795.84	1B?	
96.38	2D	96.72	2D	Ti (V)
97.66	2B?			
98.37	2D			
99.22	1B			
99.84	2D	99.75	3D	Ti V Ca
		4801.10	1D	Cr
4801.67	1B			
02.84	1D?			
03.56	2B			
04.28	1D			(La)
06.53	2D			
		07.04	1D	
08.28	2B?	08.19	2B? b	
09.23	2D	09.15	1D	La (Zr)
10.04	2B	10.08	2B? b	
		12.03	1D	(Ti)
		13.61	2B?	
		14.16	2B	
15.70	2D	15.67	4D	Zr
		17.02	2B?	
18.59	1B?	18.35	2B?	
20.62	2D	20.48	1D	Ti
23.60	2D	23.27	1D	Mn Y
		24.40	1D	(La) Zr
25.07	2B	25.09	2B	
26.45	3B? d	26.52	2B	
27.60	3D	27.65	3D	Ti V
29.49	1D	29.62	1D	Cr
30.30	4B	30.48	3B	
31.80	3D			V
		32.13	5D	
32.62	2D			V Fe
33.90	1B			
34.63	1D			
		35.14	1B? b	
37.39	1B			
		38.14	2B	
38.19	1D			
		39.60	2D?	(Y)
40.96	1D			Ti
41.60	1B?			
44.86	3B			
45.62	1D	45.65	1D	Y
46.64	1D	46.61	1D!	
47.20	1B?	47.16	1B?	
47.73	1D	47.84	1D	
49.01	2D	48.84	1D	Fe
50.25	1B?	50.20	2B b	
51.34	3D	51.43	3D	V Zr
53.26	1B			
54.36	2D			
		55.25	1D b	
55.30	1B?			
55.89	1D			Ti
57.13	1B	57.12	3B b	
		57.36	3B	
59.82	2D	59.66	3D	Fe Y
60.57	3B	60.49	2B	

λ 152 Schj.	Int	λ 19 Pisc.	Int.	Identification
4862.01	2D?			Cr
63.31	2B			
64.80	2D	4864.96	1D	V
65.94	1B?			
		66.42	1D	
67.84	3D d	67.31	2B	
67.89	3D d			
		68.11	1D	Ti
69.05	2B			
69.51	2B?			
70.54	2D			(Ti)(Cr)
71.96	2D			Fe
72.93	2B	73.12	2B b	
74.33	1B			
75.72	1D	75.82	3D	(V) Fe
		77.05	2B b	
78.44	2D	78.20	2D	Fe Ca
79.52	4B d	79.50	3B b	
80.42	1D			
81.84	5D b	81.74	5D b	V Fe
83.12	4B	83.20	2B	
		83.93	1D	Y
84.97	1D	85.04	1D	Ti
86.94	1D			(Cr)
88.04	3B	88.16	2B	
88.96	2D	89.10	2D	(Fe)
91.30	3D	91.57	1D	V Fe
92.75	1B	92.64	1B	
		93.39	1D	
95.23	1B	95.25	1B	
96.18	3D			
96.95	2B			
98.10	2B			
99.14	1B	99.18	1B	
99.54	1B			
4900.20	2D	4900.10	2D	Ti Y La Ba
01.12	1D			
		01.96	2D	
02.67	2B	02.50	1B?	
03.35	2D?	03.35	1D?	Fe
03.98	3B	03.94	1B?	
		04.95	2D	La
06.20	2D b			
08.66	3B d	08.38	1B?	
09.94	1D			
		10.54	1D	
13.95	1D	11.57	1B?	
13.95	1D	13.72	1D	Ti
14.58	1D			
		15.07	1D?	
16.15	1D			
		16.26	2B	
18.15	1B b	18.25	2B b	
19.14	2D	18.82	1D	Fe
20.88	2D	20.85	3D	(Fe) La
22.31	1D	22.20	2D	Cr
23.66	2B	23.55	2B b	
		24.44	2D	
25.92	2D	25.96	1D	
		27.07	2B? b	

λ 152 Schj.	Int.	λ 19 Pisc.	Int.	Identification
4927.74	1D?			
29.41	2B	4929.52	2B? b	
30.76	1D	30.76	1D	
34.25	2D	34.16	5D	Ba
34.67	1B?			
39.70	1D?			Fe
40.54	1D?			
		40.56	1B	
41.66	1D?			
43.65	3B			
44.25	1D?			
45.38	1D?			
		46.12	1D?	(Fe) (La)
47.36	2B	47.35	2B b	
51.35	2B			
52.19	2B			
54.80	1D?			Cr
55.53	1B?			
		57.65	1D	Fe
58.08	1D?			
59.23	1D?			
		60.07	1B?	
		63.78	1B?	
64.50	1B?			
		64.84	2D	Cr.
		69.66	1B?	
70.94	1B?			
72.00	2B			
73.34	2B			
		75.67	1D	
		81.10	1B?	
		81.82	1D?	Ti

λ152 Silj.	Int.	λ19 Pisc.	Int.	Identification
55.05.24	1B	5505.43	3B	
		06.48	8Dh	Fe
07.48	3B	07.53	3B	
		13.92	3B	
		14.94	10D	
16.00	1B	15.97	3B	
		31.55	3B	
		41.03	H	C
		85.96	H	C
86.68	1B	86.43	5B	
		88.28	3D	La
89.71	2B	89.56	2B	
		90.79	2D	
91.86	5B	91.97	3B	
		93.33	2D	
94.33	1B			
		96.21	2D	
		97.24	4B	
		98.60	3D	CaCd
		5601.41	2D	Ca
5602.61	1B	02.27	2B	
03.50	1D?	03.38	3D	
		05.73	2D	
06.49	1B			
		07.02	1D	
		10.19	1D	
		12.54	1D	
		13.31	2B?	
		14.32	2D	
		16.06	2D	(Fe)
16.89	1B	16.92	2B	
		17.76	1D	
		19.78	2D	
		23.21	1D	
		25.29	2D?	
		28.43	2D	
36.0	H	35.75	H	C
36.14	2B?	36.06	2B	
36.87	2D	36.99	1D?	Cd
37.76	2B	37.88	1B	
38.39	2B	38.33	1B	
39.46	3D	39.48	1D	
40.58	4B	40.59	3B	
41.49	2D	41.63	1D	
44.25	2Dh	44.54	2D	Ti
46.10	1Bd	45.78	1Bd	
47.12	2D	47.16	1D?	Ti
47.98	2Bd	47.86	1B	
48.90	1D	48.63	1D?	Ti
49.46	2B?	49.41	1B	
50.31	1D	50.28	1D	
51.74	4Bd	51.61	2Bh	
53.16	5D	53.31	2D	
54.56	3Bh	54.38	2Bh	
55.40	2B			
56.39	2D			
57.35	2D	57.56	1D	V(Sc) La.
		58.25	1B	
60.53	1B	60.50	1B	
61.42	4D	61.36	1D	

λ152 Silj.	Int.	λ19 Pisc.	Int.	Identification
		5662.10	1B	
5662.64	2Bh			
63.97	1B?	64.02	1B	
64.61	1D?	64.68	1D	Zr
65.26	2B?	65.39	1B	
65.87	2D			
66.77	5B	66.62	2B	
67.47	3D	67.51	1D	Fe
68.33	3B	68.32	1B	
69.57	4B	69.21	1B	
70.28	1D	70.32	1D	Na
71.79	3D	71.87	1D	Sc
72.94	3B	73.03	3B	
		74.02	3Bh	
75.16	5Dh	75.35	5D	Ti(Na)
76.17	5B	76.24	2B	
77.33	3D	77.26	1D	
78.65	3B			
79.06	5B	79.06	3B	
80.10	4D	80.10	1D	
81.10	2B			Ba
81.52	2B			
82.44	3D	82.84	1D	Na
83.75	4B	83.81	2B	
84.90	3D	84.73	1D	
		86.79	2D	Fe Sc.
87.22	3D			
		87.66	1B	
		88.39	1D?	(Na)
89.12	2B	88.98	1B?	
89.73	1D	89.57	1D?	Ti
91.29	3D			
92.25	3B	92.16	2B	
92.80	3B			
		93.98	4B	
94.30	2B			
95.58	2B	95.56	2B	
96.48	4D	96.52	4D	(La)
97.45	6B	97.60	3B	
98.53	1D?	98.74	1D?	V Cr Mn
5700.28	2D?	5700.38	1D?	Mn Sc
01.32	2B	01.20	1B	
01.90	2D?	01.99	2D	(Cr)
03.57	3D	03.60	1D?	V
04.64	3B	04.58	3B	
05.62	3B	05.75	2B	
06.39	1D?			
07.42	4D	07.25	2D	V
08.50	1B?	08.17	2B	
		08.99	3D	(Fe)
10.10	2B	10.30	5B	
11.15	1D?			
		12.04	4D	Ti Fe Sc (La)
12.64	2B			
13.43	2D			
14.18	2B			
		14.63	1B	
16.09	4B	16.33	2B	
		17.01	1B	

λ152 Schj.	Int.	λ19 Pisc.	Int.	Identification
5717.42	2B			
19.62	2B			
21.55	3Db			
		5721.92	1D	
23.14	2B			
		23.38	4Bb	
23.75	3B			
		24.82	1B?	
25.99	2B			
		26.24	1B	
27.46	1D	27.26	2D	Ti V Cr
		28.49	1B	
29.68	1B	29.70	1B	
31.10	3Db	31.25	3D	V
32.25	1B?			
33.19	2D?b			
35.42	2B			
36.03	1D?	35.92	1D	Zr
36.65	2B	36.66	1B	
37.62	2D			
40.45	4B	40.32	1B	
		41.09	1D?	
42.10	1D?			
44.70	2D	44.55	2Dd	La
45.83	2B	45.62	1B	
46.60	1B?	46.50	1B?	
47.36	2D			
48.05	1B?	47.92	1B	
49.07	3D	48.97	3D	
		50.22	1B?h	
51.40	1D?			
		52.17	1D	
52.53	1D			
53.23	4B	53.34	2B	
54.80	3D	54.67	2D	
56.04	6B	55.95	3B	
		57.74	2B	
58.74	2D	58.71	2D	
60.06	2B	59.99	3B	
61.50	3D			
62.81	2B	62.75	1B	
63.75	1D	63.65	1D?	
		64.80	1B?d	
66.09	1D?	66.02	1D?	(Ti)
66.95	2B	67.04	3B	
67.99	2B	67.89	3B	
68.98	1D?	69.08	1D?	La
70.14	1B?	70.13	1B?	
71.50		70.92	1D?	
71.50	2Db			
		72.01	1D?	
72.90	5B	72.92	1B	(Ti)
74.45	1D			
75.57	1B?	75.62	2B	
76.55	1B			
78.18	4Db			Ba
79.70	5B	79.75	5B	
80.56	1B?			
81.52	2D	81.57	1D?	Cr.
82.66	1B?			

λ152 Schj.	Int.	λ19 Pisc.	Int.	Identification
		5783.44	2B	
		84.85	1D?	Cr
5785.69	4Db			(Ti) Cr
87.68	6B	87.68	2B	
89.19	3D	89.03	2D	La
		90.18	1B?d	
90.55	1B			
		91.33	1D?	La
91.89	4B			
93.74	1D	93.95	1D?	
95.23	1Bb	95.32	2B	
96.05	1D?			
		96.70	3B	
98.29	4Db	97.98	4D	(La) Zr
		99.57	4Bd	
5800.33	5Bh			
01.18	1D	5801.24	1D?	
		02.37	2B	
02.92	3Db			
04.53	2Bh			
		05.33	2B	
05.96	3D	06.32	2D	La Ba
07.03	3B	07.28	2B	
08.18	2D	08.40	1D	La
09.18	1B	09.45	2B	
		10.30	2B	
11.31	1D	11.39	1D	
11.92	1B!			
		12.75	1D?	
13.63	1B	13.85	2B	
14.34	1D?			
15.40	8B	15.38	2B	
16.58	3D	16.67	1D	Fe Mn
		20.02	3Bd	
20.40	1B			
20.88	1B			
21.79	2D	21.63	1D?	
		22.36	1B	
23.73	2D	23.54	3D	
		24.68	2Bd	
25.81	3B			
27.34	4Dd			
		27.54	1B?	
		28.22	2B?	
28.53	3B			
30.41	1B?	30.56	1B!	
31.10	1D?			
		31.75	1D?	
		33.89	2B	
34.37	1B?			
35.26	1D	35.28	1D?	
		36.53	2B	
37.05	3Bb			
		37.25	2B	
38.66	2D	38.80	1D?	
		39.49	1D	
40.19	1B?			
		40.49	2B	
41.49	1D?			
		42.56	2B	

λ152 Schj.	Int.	λ19 Pisc.	Int.	Identification
5843.59	1B	5843.57	2B	
45.05	1D?	44.99	1D?	
45.76	2B	45.70	2B	
46.74	1D			(V)
48.47	4B	48.52	3B	
50.05	4Db			
		50.66	2D	
51.67	4Bd	51.74	2B	
		53.86	2D	Ba
54.31	2Db			
		55.09	1B?b	
56.18	2Bd			
		56.67	2B	
57.36	1D?	57.42	1D?	
58.61	1D?	58.62	1D?	
59.07	1B?	59.12	1B?	
60.05	1D	60.16	2D	
		61.42	1B?d	
62.59	1B	62.83	1B?	
		63.70	1D?	La
64.50	1D?			
		65.28	1B	
65.63	1B!			
66.48	1D	66.41	1D?	Ti
		67.24	1B!	
		68.23	1D?	
68.54	1B?	70.69		
70.93	1B	70.69	1B?d	
71.84	1D	71.74	1D	
72.64	2B	72.69	1B?	
73.65	2D	73.66	1D	
74.71	1B	74.72	2B	
		75.21	3B	
75.62	1B			
77.07	6B	77.21	4B	
		80.04	1D	Cd
80.52	1D?b			La
82.44	7B	82.59	5B	
84.47	1D			
85.48	1B			
		86.06	1D?	
87.39	3B	87.37	2B	
90.13	6Db	89.82	10Db	Na
92.12	1B	92.18	1B?	
96.12	4Db	96.26	8Db	Na
99.18		98.45	1B?	
99.18	1D?	99.38	1D?	Ti
5900.27	1B	5900.45	1B	
01.50	1D	01.55	2D	
		02.94	1B	
		03.76	1B	
05.17	1D	05.01	1D	
06.20	4B	06.25	2B	
09.81	2B	09.62	1B	
		11.36	2Bd	
		15.04	1B?	
16.52	1D	16.25	1D?	Fe
17.33	2B	17.40	1B	
		19.29	1B?	
20.36	1D			

λ152 Schj.	Int.	λ19 Pisc.	Int.	Identification
5921.51	1B			
		5923.57	2B	
23.62	1D			
		25.00	2D	
26.31	1B?			
		28.02	1B?	
		29.88	1B?	
31.62	2B	31.63	2B	
32.98	1D	32.83	2D	
		34.10	1B?	
34.86	1B?h			
		35.10	1D?	Fe
38.06	1D	37.97	2D?	Ti
		39.37	3Bd	
		40.83	2D	
		42.26	1B	
43.95	1B	43.82	1B	
45.35	1D?	45.07	2D	
46.27	1B	46.38	2B	
		47.41	2B	
48.97	1D	49.07	1D?	
51.90	1B	51.99	2Bb	
54.79	1D	55.08	3D	
56.21	1B?	56.11	1B!	
58.97	1B?h	59.30	1B	
60.58	1D	60.48	2D	
		61.59	1B?	
62.31	1Bh	62.38	2B	
64.87	2B	64.88	2B	
65.90	1D?			Ti
		68.02	1B?	
		69.13	2D	
		70.48	3Bd	
70.93	1B?			
71.74	1D?			Ba
72.83	1B			
		73.01	1Bd	
73.50	1B			
74.56	1D			
76.59	1B?b			
		77.17	1Bb	
		78.81	1D?	Ti
		80.32	1B?	
80.78	1D?			
81.83	1B	81.79	1B?	
84.72	2D	84.57	3D	Fe (Zr)
85.96	1B	85.73	3B	
		87.26	2B	
		88.69	2D	
89.31	1B			
		89.80	1B	
91.95	1B?h	92.28	1B?	
		93.71	1D?	
94.26	1D			
		95.60	1D?	
96.74	2Bh	96.92	1Bb	
6001.96	1Bh	6001.94	1B	
		03.54	1B?	
08.48	1D	08.66	1D	Fe
09.38	1B?			

λ152 Schj.	Int.	λ19 Pisc.	Int.	Identification
		60.09.74	1B	
		12.06	1B	
6015.18	1D			
		16.10	1B	
18.82	1B	18.95	1B	
22.36	1Bh	22.61	2B	
		23.71	2D	Fe
		25.43	1D?	
27.83	1B	27.86	1B	
29.80	2Bd	29.85	2Bd	
31.54	2D	31.45	3D	
32.89	1B?	33.12	1B	
		34.69	1D?	
		35.78	1B	
		36.39	1B	
37.52	1D?	37.61	1D?	
38.42	1B?	38.66	1B	
39.74	1D	39.66	1D?	V
		42.37	1B?	
42.57	1D?			
43.83	1B?	43.63	1B?	
44.64	1D?	44.87	1D?	
45.27	1B?			
46.66	1B?h	46.76	3B	
49.00	3Db	48.91	3D	
51.31	3B	51.14	3B	
52.79	1D	52.75	1D?	
54.53	1B?h	54.71	1B?	
55.78	1B?	55.63	2B	
58.32	3Db	57.93	3Dd	C V
		59.86	1B?	
		62.09	1B?	
62.76	1B?h			
6463	1D			Ti
		65.52	1D	Fe
		67.52	2B	
		68.57	2B	
69.80	1D?			
		70.21	2D?	
		71.39	1B	
71.48	1D			
73.09	3Bd	73.05	5Bd	
75.18	2D	75.23	2D?	
76.18	1B	76.47	1B	
		78.82	1B	
80.71				
80.71	1B			
81.50	1D?	81.65	1D	V
82.75	1Bd			
		83.16	1B	
84.36	3Dd			Ti
85.66	3B	85.94	1B	
87.86	3B			
		88.48	2B	
89.69	2D?	89.90	1D	V
90.88	1B?			
		91.58	2B	
93.55	1B?			
		95.30	2B	
		96.66	2B?	

λ152 Schj.	Int.	λ19 Pisc.	Int.	Identification
		6099.11	2D	Cd
6100.04	3Dh			
		61.01.39	3Bd	
01.77	2B			
		02.88	1D	Fe Cr Ca
05.54	3Bh	05.64	2B?h	
07.56	2D			
		08.30	2D	
09.67	4B	09.79	3B	
11.87	2D	11.53	2D	V Cd
13.22	1D			
14.40	1B			
15.72	1B			
		16.70	3Bh	
21.72	3Dh	21.87	3Dh	C Ca Zr
23.04	3B	23.37	3B	
		28.16	1D	Fe
30.98	4B	30.81	4B	
		34.72	1D	Zr
35.30	1D?			V
		39.84	1B	
40.44	1D?			
4229	1D	42.02	1D	Fe Ba
		44.71	3Bd	
		49.79	1D	(V)
		53.16	1B	
		54.78	2D?	Na
55.92	1B			
56.79	1B	56.78	1B	
59.02	1D?			
59.88	1B	59.88	2B	
		61.72	2D	(Ca)
		63.03	1B?	
67.30	4Dh	1		
		67.55	2B	
68.77	1B	68.30	2B	
70.22	1D?	70.13	2D?	V Fe
72.16	1B?	71.96	2B	
73.21	2D?	73.42	1D?	Fe
74.47	1B?			
		75.05	2B	
75.93	1B?	76.13	2B	
79.40	1B?	79.49	2B	
83.28	1D	83.8 - 90.2	B group	
84.32	2B			
91.59	9Db	91.95	7D	C Fe
94.34	3B	94.35	2B	
95.97	1D			
		97.24	1B	
98.39	2B	98.48	2B	
		6200.73	1D?	Fe
6201.13	1D?			
02.00	2B	01.95	1B	
		03.64	3B	
05.63	2B	05.48	2B	
07.29	2D	07.53	1D?	
11.83	1B			
12.92	9B			
14.33	2D	14.14	3D	V

λ152 Selj.	Int.	λ19 Pisc.	Int.	Identification	λ152 Selj.	Int.	λ19 Pisc.	Int.	Identification
6215.84	1B	6215.67	1B?				6312.32	2D	Ti La
		16.57	1D?				14.80	2B	
17.32	2D?				6315.35	5Bd			
19.15	2B	18.96	2B				15.99	3B	
21.14	1D				17.48	1D	17.69	1D	Fe
23.75	1B	23.79	1B?				19.87	1D?	(La)
25.02	2D	25.15	1D	(V)	23.09	1B!	22.85	2B	
26.98	3B	26.98	3B		24.39	1D	24.51	1D?	
		28.63	1B		25.73	5B			
31.43	4D	31.64	3D		27.54	3D?	27.34	1D?	Cr
33.44	1D?			V	29.70	8Bb	29.55	7Bd	
34.20	3B				32.48	1D			
		3463	1B		34.91	1B?			
36.58	1B	36.50	1B				35.72	1D?	Ti Fe
		38.24	1B?d				37.63	1B?h	
		39.85	2D	Sc	38.13	1B? d			
41.12	3B	41.17	1B		39.44	1D	39.46	1D	
		42.79	1D?	V	40.53	3B	40.59	1B?	
45.99	1D	45.92	1D	Fe	44.44	1D			Fe
47.26	1B	47.26	2B		46.13	3B	45.90	1B?	
48.58	1B	48.21	1B		47.82	1D?	47.46	1D	
50.14	1D	50.00	2D	La	50.38	2D	50.40	1D	(Ba)
52.32	2B	52.52	1B				52.62	3B	
53.91	1D			Fe	52.94	7Bb			
55.46	2B	55.55	1B				53.47	2B	
58.10	1D	58.37	5D	Ti V	56.45	1D?			
59.11	1B				58.75	2D	58.62	4Db	Fe(La)
61.21	2Dh			Ti V Cr	60.58	2B	60.47	1B	
63.30	1B	63.28	3B		62.38	1D	62.21	2D	(Fe)(Cr)
64.92	1D	64.75	1D?	Fe	63.90	2B	63.58	1B	
68.01	1B	67.76	2B				66.56	1D	Ti
69.58	1D?	71.41			67.66	1D			
		71.41	1B		69.15	1B	69.06	2B	
73.65	1B	73.70	1B		70.81	2D?	70.74	1D?	
75.50	3D	75.31	2D		72.62	4B	72.99	3B	
77.06	2B				75.09	2D	75.40	1D	
		77.70	1B?		77.48	1Bh			
		78.89	4B		78.87	2D	78.73	2D	Sc
81.34	4D	81.21	3D	(Fe)	80.09	3B	80.36	2B	
83.54	2B	83.61	4B		82.31	1D?			
85.13	2B						83.69	1D?	
87.08	4D	86.85	2D		84.30	1D?			
89.31	2B	89.14	5B		85.83	1B	85.82	2B	
90.61	1B?				88.68	2D	88.47	2D	
		91.08	3B		90.98	2B	91.25	3B	
		93.14	1D	V	93.39	1D?	93.60	2D	Fe
93.57	2D				94.62	1B?			
		94.66	1B		98.64	1B	98.78	1B	
95.35	3B				6400.20	1D?	6400.14	1D?	Fe
97.48	2D			Fe	03.57	3D	03.21	1D	
98.79	3D				05.83	4B	06.07	2B	
		99.45	1D	Zr	07.67	1D?	07.78	1D	Fe
6300.30	2B				08.84	1B?	09.01	1B	
		6300.91	1B		10.68	1D?	10.57	1D?	La
01.32	1B				12.29	1B?	11.99	1B	
		02.62	1B		14.12	3D	13.87	2D	(Sc)
04.51	2B	04.39	1B		17.04	3Bb	17.13	3B	
05.91	4D	05.91	4D	Sc	19.25	1D	19.42	1D	
07.85	3B	08.00	6B				23.06	3B	
09.35	2Bd				25.70	2D	25.36	2D	

λ152 Schj.	Int.	λ19 Piscium	Int.	Identification
6427.66	1B	6427.66	3B	
29.05	2B			
		29.79	2B	
31.09	2D	30.80	2D	Fe
41.05	1B?	41.32	2Bd	
43.85	3D	44.01	3D	
46.47	9Bb	46.74	7Bb	
49.21	1D			
		50.25	4Db	Ca
		52.86	2B	
53.87	1D			
		5439	1B	
55.57	3B			
58.27	2D			
60.06	1B	59.67	3B	
61.45	3B	61.02	3B	
63.70	1D?			
66.46	1D			
67.85	1B	68.42	2B	
71.00	1D	70.81	1D	(Zr)
72.61	3B	72.71	2B	
75.06	1D?	74.74	1D?	
		76.45	1B?	
77.65	1B			
78.75	1B?			
		79.64	1B?	
81.01	2D?			
83.10	1B			
		87.76	1B	
91.21	2B	91.55	2B	
94.21	1D	93.86	3D	Ca
95.54	1B	95.56	1B	
97.30	2Db			Ba
		98.14	2D	La
99.90	1D?			Ca
		6500.6	1B?	
6501.4	1B?			
		02.9	1D?	
04.3	1B?			
		05.1	1B?	
08.1	1B?			
		09.6	2D	
10.6	2D			
13.4	1B	13.3	2B	
		15.1	1D	
16.3	1B			
18.4	1D			Fe
		21.4	2B	
24.9	2B	25.1	2B	
27.4	2D	27.3	3D	La Ba
30.6	1B	30.4	1B	
		323	1D	(V)
33.4	2D			
35.9	2B	35.8	1B	
		37.7	1D	Cr
39.8	4B	40.1	3B	
42.1	1D	42.4	1D	
		44.3	1B	
47.8	2D	47.1	1D	
		49.8	2B	

λ152 Schj.	Int.	λ19 Pisc.	Int.	Identification
6551.6	1B	6551.9	2B	
53.6	1D	54.2	3D	Ti
58.1	1D	58.6	2D	
60.0	2B			
61.4	2B	61.9	3B	
67.8	1B	68.3	3B	
69.9	1D	70.3	3D	
71.9	1B	71.8	1B	
75.5	1D	74.7	1D	Fe
79.0	1B			
80.6	3B			
83.2	2D	84.2	2D	
86.1	1B			
		87.3	2B	
90.0	1B			
		93.2	1D	Fe
94.5	1B			
96.5	3D			
6604.8	2B			
08.1	2B			
11.5	1D?			
15.6	4B			
		6618.3	2D?	
24.6	2D?	24.6	2D	V
27.9	1B			
30.9	2D?	31.5	2D	
33.2	2B			
40.0	1D?	40.3	1D	
41.3	1B			
45.1	1B			
54.5	3B			
		55.8	2B?	
57.7	1B			
		80.7	1B	
88.3	1D	88.6	3D	
91.4	1B	91.8	3B	
95.7	1B			
		98.4	2D	
		6701.9	1D	
6708.4	1D			
		10.9	2D	
15.3	1D?	15.9	2D	
22.2	1D			
24.4	3B	24.8	2B	
		28.8	1D	
36.5	3B	37.3	1B?	
43.1	2Dh	44.3	1D	Ti
49.9	3B	50.8	2B?	
		54.8	3Db	
56.0	2D			
59.3	2Bd	59.5	2Bd	
62.2	1D?	62.5	1D	Zr
64.5	2Bb			
68.6	1D			(Zr)
88.4	2B	88.3	2B	
95.9	2D	94.9	3Db	
97.7	2Bd			
6804.1	2Bb			
10.2	1D			Fe
23.7	2Bd			

λ152 Schj.	Int.	λ19 Pisc.	Int.	Identification
6837.0	1B?			
39.7	1D?			
		6847.0	1D?	
66.2	2D?	66.9	1D?	
74.0	1D	74.5	1D	
84.2	1B			
91.3	1D			
		92.7	1D?	
97.2	1B?			
6904.1	1B?			
11.4	2D	6911.0	2D	
16.0	2D?			(Fe)
26.5	3D			
33.4	2D			
43.4	2Dh			

Table IV
α Orionis

λ	Int.	Identification	Class'n	λ	Int.	Identification	Class'n	λ	Int.	Identification	Class'n
5658.88	1	Fe		6049.26	1		3D	6494.70	2	Fe Ba	
82.64	1d	Na	2D	63.16	2d	Ba	1B?b	97.18	2	Fe Ba	2Db
86.47	1	Fe		65.44	2	Fe	1D	99.41	1	Ca	1D?
88.19	2	Na	1D?	81.44	1	V	1D	6537.99	1	Cr	1D
94.85	1	Cr Ni		82.72	1?	Fe	1B	43.69	1?		(1B)
96.15	1		(4D)	90.01	1b	Ti V	1D	62.97	4	H	
98.22	1	Fe Cr	(1D?)	92.94	1b	Ti?	(1B?)	74.67	1		1D
5700.13	1	Sc	1D	97.24	1			93.76	1	Fe	(1D)
01.86	1d	Fe?	2D	6102.71	3b	Ca Cr	1D				
03.51	1	V	2D	16.92	1		3B				
06.53	2d	V	1D?	19.90	2						
09.36	2	Fe Ni?	3D	22.29	2	Ca	(3Db)				
11.27	1	Fe Ni?	1D?	26.33	1	Ti					
12.04	2	Ti	4D	34.21	1						
15.04	1	Ti Fe Ni		36.77	1	Fe					
18.14	1b	Sc?		37.80	1	Fe					
24.07	1	Sc? V	3B	41.76	2	Fe Ba	1D				
27.23	2b	Ti V	2D	43.40	1	Zr?					
31.28	2	V	3D	49.31	1b		(1D)				
34.10	1			51.87	1	Fe?					
35.49	1	Zr?	2B	62.40	2	Ca?					
37.03	1	V	(1B)	91.46	2?	Ni Fe	8D				
39.28	1	Ti?	2B	6258.17	2b	Ti	3Db				
39.98	1		(2B)	61.21	2	Ti	2Db				
43.41	1	V	1B	62.36	2						
48.17	2	Fe Ni	1B	65.16	2	Fe	1D				
52.99	1	Fe	3B	66.36	1	V					
54.62	1	Ni	2D	97.68	1	Fe	2D				
75.02	1	Fe		6305.88	1	Sc	4D				
78.33	1	Fe	4Db	11.81	1b		(2D)				
82.25	1	Fe	(1B?)	14.80	1	Ni	2B				
86.02	2	Ti Cr	(4Db)	22.64	1	Fe	1B				
90.91	2	Cr	(1B)	25.01	1	Cd					
97.82	3	Zr?	} 4Db	27.71	1	Ni	2D				
98.40	2	Fe		30.45	1d	Cr?	(7Bb)				
5804.32	2	Ti	2Bb	35.90	3b	Ti	1D				
53.72	1	Ba?	2D	44.72	2		1D				
57.49	2	Ca	1D?	58.68	2	Fe	3D				
59.61	1?	Fe		62.74	1	Cr Fe	(1D)				
62.47	1	Fe	1B	78.93	2		2D				
66.35	1	Ti	1D	92.55	1						
79.98	1b	Zr?	1D	93.82	2	Fe	1D				
89.92	3b	Na	8D	6400.37	3	Fe	1D				
93.93	1			08.04	1	Fe	1D				
96.03	3b	Na	6D	11.72	1	Fe	(1B)				
99.37	1	Ti	1D?	13.44	1	Sc	(2D)				
5903.15	1		1B	19.04	1		1D				
18.44	1	Ti		22.47	2		(3B)				
40.63	1		2D	25.82	1?		2D				
41.71	1	Ti		33.61	3						
44.74	1		(1D)	38.73	1	Cd					
56.42	1		1B	39.84	1						
76.67	1	Fe	1B?b	49.85	3	Ca	(4Db				
78.66	1	Ti	1D?	55.81	1?	Ca	3B				
60 84.49	1		2D	62.77	2	Ca Fe					
6008.07	2b	Fe	(1D)	66.86	1		1D				
86.74	1	Mn.		69.24	1d						
31.54	1		2D	71.41	1	Ca?	(1D)				
36.37	1		1B	74.32	2b		1D				
39.73	2b	V	1D	82.94	2b	Ni Ba	1B				

Part II. Variations in the Spectra of Class N Variables

Introduction

It would seem natural to suppose that a star whose light varies by a factor five or ten should show some changes in its spectrum during the variation, unless this is effected through the occultation of the star by opaque matter. The long period variables of Class Md have been studied with particular reference to their spectral changes by a number of observers, notebly Sidgreaves[1], Stebbins[2], Plaskett[3] and Merrill[4]. Although our knowledge of these stars is still far from satiafactory, the general character of the variations in their spectra has been determined. The variables of Class N have not heretofore been examined in this connection.

The purposes of the present investigation are:

(1) To study the Class N variables for spectral chanhes.

(2) To correlate any variations which are detected with the light changes in the stars.

(3) To compare the spectral variations in the Class N stars with those in the stars of Class Md.

Observations

The following Class N variables were selected for observation: U Cygni, RS Cygni, R Leporis, RV Cygni, Y Tauri, U Camelopardalis, S Scuti and V Aquilae. All these stars have maxima near the six and a half or seventh magnitude and minima of about the ~~ninth an~~ eighth to tenth magnitudes. On account of their faintness it was necessary to employ low dispersion in photographing the spectra.

In the visual region spectrograph 6, described in Part I, was used for most of the work. This gives quite low dispersion and very few absorption lines can be seen, but some of the groups of bright lines are visible on the plates.

The sodium lines are recorded as as single strong line and the group of carbon bands at 5635A is well shown. A few spectrograms near the maxima of some of the stars were obtained with spectrograph 5.

In the photographic region spectrograph 7 was used. The definition given by this instrument is naturaully not so good as that given by a slit spectrograph of the same dispersion, but the speed is very great, good spectrograms of star of the elevehth photographic magnitude being ontained in ninety minutes. The slitless spectrograph possesses an advantage over slit spectrographs attached to refractors for the purpose here used, in that the relative intensities of the various portions of the spectrum are unaffected by such factors as focus of the image on the slit and atmospheric dispersion, which effects might causes all the light of one color to fall in the slit while not all that of another would enter.

The principal spectral changes in the different stars are tabulated below. Since these stars vary irregularly or with long periods , it has been possible to observe only two or three in all their light phases.

U Cygni Range 6.7-10.8 mag. Period 461 days.

Table I Visual Region Spectrograph 6

(Insert Table I)

In the first and second columns are tabulated the dates of the observations and the estimated magnitudes of the star. The intensities of the bright lines $H\alpha$ and 5845A are recorded in columns three and four. Column five contains the widths of the single dark line representing the D lines of sodium. The numbers in column six indicate the intensity of the carbon band at 5635A, expressed as a ratio of the intensities of the continuous spectrum at 5680A and 5600A.

The spectral changes between March 7 and July 25,1917, recorded by the

first two plates tabulated above, are confirmed by observations taken with spectrograph 5 on march 15 and June 10 of the same year.

Table II Photographic Region Spectrograph 7

(Insert Table II)

The arrangement of the material in Table II id the same as that in Table I with the exception of column six. The numbers in this column serve as a measure of the relative strengthening of the spectrum in the longer wave-lengths. They express the ratio of the spectral intensities at 4780A and 4620A, these two wave-lengths being chosen on either side of the carbon band at 4738A.

RS Cygni Range 6.7-8.9 mag. Period irregular.

Table III Visual Region Spectrograph 6

(Insert Table III)

Table IV Photographic Region Spectrograph 7

(Insert Table IV)

R Leporis Range 6.1-9.7 mag. Period 436 days.

Table V Visual Region Spectrograph 6

(Insert Table V)

The wave-length of the bright line, 5845.3A, was derived from a plate taken 1917,Feb.7, with spectrograph5. $H\alpha$ was recorded on this plate.

Two plates with spectrograph 7 gave the following data:

1919 Oct. 19 Mag.8.8 No bright lines Plate underexposed
1920 Jan. 20 Mag. 7.7 $H\beta$; int.4.

RV Cygni Range 7.1-9.3 mag. Period irregular

Table VI Visual Region Spectrograph 6

(Insert Table VI)

A plate taken with spectrograph 5, 1917 Oct.22, does not show $H\alpha$.

Six plates obtained with spectrograph 7 between May 6 and Oct. 31,1919, record no changes in the spectrum. The hydrogen lines do not appear.

Y Tauri Range 6-8 mag. Period irregular.

Table VII Visual Region Spectrograph 6

(Insert Table VII)

Three plates obtained with spedtrograph 7 from Sept.2,1919 to Jan. 20,1920 do not show any changes in the spectrum. No hydrogen lines are recorded.

U Camelopardalis Range 7.5- 9 mag. Period irregular

Table VIII Visual Region Spectrograph 6

(Insert Table VIII)

Four plates obtained with spectrograph 7 from Aug,8, 1919 to Jan.20,1920 recoed no definite spectral changes. The hydrogen lines are not present.

S Scuti Range 6-8 mag. Period 23 days ?

Throughout the observations extending from May 11,1919 to March 29,1920 the magnitude of the star remained practacally constant at 6.8. No spectral changes were observed and none of the hydrogen lines were recorded.

V Aquilae Range 6.5-8.0 mag. Period irregular

As in the case of S Scuti, V Aquilae did not vary appreciably in brightness from May 3,1919 to April 3,1920. There is some evidence that Hα appears and varies slightly in intensity. No changes are found in the photographic region.

Discussion of Observations

The material of this investigation is not sufficiently extensive to permit of a definite statement regarding the spectral changes in the Class N-variables. We can, however, present a preliminary summary of the variations and consider it subject to modification by later observations. The data are based primarily on the spectrograms of U Cygni, RS Cygni and R Leporis, The observational evidence from the other stars is fragmentary, but it agrees, in nearly all cases,

with the more complete results. The charecteristic variations in the spectra are summarized below.

(1) The hydrogen lines are absent or very faint at minimum light, As the star approaches maximum, $H\alpha$ and $H\beta$ appear, followed by $H\gamma$, $H\delta$ and possibly $H\zeta$. These lines reach their greatest itensities shortly before maximum light. They then gradually fade out, $H\delta$ first, followed by $H\gamma$, $H\beta$ and $H\alpha$, probably in the order named. By the time the star has fallen one or two magnitudes below maximum, all these lines have disapeared.

(2) the D lines of sodium are broad and frequently blended together. At minimum light they are exceptionally wide and gradually become narrower as the star approaches maximum. With the decline to minimum they broaden again, probably attaining their greatest width of 50A to 100A at minimum light.

(3) There is a tendency for the spectrum to become relatively strong in the red as the star decreases in brightness. This is very marked in U Cygni. At minimum light the region near $H\alpha$ is more than twice as bright, relative to the spectrum at 5700A, as when the star is at maximum.

(4) A decrease in the intensity of the carbon absorption near maximum light is observed in some cases. This is especially true of the band at 6191A.

(5) Certain bright lines of unknown origin, notably one at 5845.3A, appear to vary in intensity. Owing to the lack of detail given by the low dispersion used, this fact cannot be regarded as definitely established.

The spectral variations as outlined above are similar in their general character to those occurring in the Md variables. The principal features of the variations in the Class Md stars are as follows:

(1) The hydrogen lines appear shortly before maximum light, $H\delta$ first, followed by $H\gamma$ and $H\zeta$, and probably $H\beta$ and $H\alpha$. They reach their greatest intensity shortly after maximum light, and do not begin to fade until the star

has fallen one or two magnitudes in brightness.

(2) It is difficult to observe variations in the D lines of sodium in the Class Md stars because they fall within a titanium oxide band, which, in o Ceti at least, varies in intensity, producing practically complete absorption at minimum light. Stebbins, however, noticed that in this star, the low temperature line at 4227A broadened as the star decreased in brightness.

(3) The titanium oxide bands become more prominent as the stars approach minimum.

(4) Stebbins observed, in o Ceti, a relative strengthening of the less refrangible region as the star approached minimum. Some of the plates which I obtained at the recent maximum and decline to minimum demonstrated the existence of this effect in the region 4860A-6800A.

(5) Certain bright lines, some of which are ascribed to iron and silicon, appear in the Class Md stars near the time of maximum.

A comparsion of the spectral variations in the Class N stars with those in the Class Md stars reveals a striking similarity. The principal features of the variation correspond in the two tpyes. The few differences in such details as the relative strength of the hydrogen lines in the two stars, are comparatively unimportant.

Conclusions

The close relation between the spectral variations in the Class N and Class Md stars has been established. In tpye of light variation, also, they are similar. From these considerations it seems quite probable that the main causes underlying these phenomona are common to both classes of stars.

The "veil theory" proposed by Merrill with reference to the Class Md stars,

seems to explain the principal features of the variation in a fairly satisfactory manner.This theory suggests that the danse outer portions of the stellar atmospheres condense to form clouds of small particles. These clouds exercise a screening effect on the stars light, which, if the partiwles are of the proper size, will be most effective in the shorter wave-lengths.After a time the imprisoned radiation heats the clouds, causing them to evaporate. A period of relatively unobstructed radiation then ensues, after which the clouds form again. These changes may easily be periodic. Merrill also suggests that the bright hydrogen lines may have their origin in the electrical effects arising from the evaporation of the clouds.

A few of the observed phenomena such as the relative faintness of H_α and H_β in the Class Md stars and the variations in strength of the sodium lines in the Class N stars, are apparently not accounted for by the "veil theory". In general, however, it explains the light and spectral variations in the long period variables better than any other theory that has been proposed.

Summary

The preceeding investigation is concerned with variations in the spectra os certain Class N variable stars.

(1) A number of spectral variations in the Class N stars have been discovered and correlated with the light changes.2

(2) The main features of the variations in the Class N and Class Md variables are similar, from which we infer that the same causes underlie the variations in both tpyes of stars.

(3) The "veil theory" proposed by Merrill explains the main features of the variations.

It is a pleasure to express my gratitude to Dr. Campbell for the liberality with whiwh he has accorded me the use of the Observatory equipment and to

Dr. Paddock and other members of the staff, who secured a number of the spectrograms.

Footnotes

1. Mon.Not. R.A.S.,58,344,1898.

2. L.O.Bull.,2,78,1903.

3. Jour. R.A.S. Canada,1,45,1907.

$. Publ. Detroit Obs.,2,45,1916.

5. Ibid.,2,45,1916.

Table I Visual Region

Date	Mag	Hα	5845A	D (width)	Carbon Band 5635A	Remarks
1917 Mar 7	7.2	10	0	20A	1.5	
July 25	8.1	2	1?	30A	2.0	
July 26	8.1	0	1?	28A	3.0	
Oct 18	9.5	0	1	50A	3.0	Carbon band at 6191 A Spectrum twice as strong at Hα as at
1919 Apr 29	8.2	?	—	24A	1.5	Plate badly overexposed
May 11	7.7	3	3	28A	2.0	Carbon band at 6191 A B line int 1 at 5591 A
May 25	7.5	7	2	20A	1.5	B line at 5591 A?
June 5	7.6	9	0	20A	1.5	B line at 5591 A?
June 8	7.6	10	0	—	—	Plate underexposed
July 19	7.4	10	1	20A	1.5	
Sept 12	6.8	15-20	1	16A?	1.5	Poor focus
Nov 11	7.4	5	0	16A?	2.0?	
1920 Jan 3	8.2	2	0	20A?	2.0	Spectrum relatively strong at
Mar 29	9.2	?	—	100A	3.0	Carbon band at 6191 A Spectrum 2.5 times as strong at Hα

Table II Photographic Region

Date	Mag.	H_β	H_γ	H_δ	Int 4780A / Int 4620A	Remarks
1917 Apr 29	7.2	14	—	—	—	Spectrum not in center of plat
May 12	7.5	10	16	2	1.0	Trace of H_δ
June 26	7.9	2	2	0	1.0	
July 21	8.1	trace	trace	0	1.4	
July 30	8.1	?	0	0	1.7	
1919 Apr. 8	9.0	0	0	0	2.0	
Apr. 20	8.6	0	0	0	2.0	
May 6	7.8	5.	0	0	2.5	
May 22	7.5	12	4	0	1.2	
June 4	7.6	9	9	0	1.1	
June 23	7.5	8	7	0	1.4	
July 26	7.4	16	14	?	1.1	
Sept. 2	6.9	15	16	1	1.1	
Oct 31	7.1	10	15	2	1.1	
1920 Jan 20	8.2	0	0	0	1.7	

Table III Visual Region

Date	Mag	Hα	5845 A	D (width)	Carbon Band 5635 A	Remarks
1917 Mar 6	7.8	2	2	22 A	1.7	
July 25	7.0	0	0	25 A ±	2.0 ±	underexposed
Oct 19	8.2	0	1?	40 A ±	1.7 ±	Spectrum 1.3 times as strong at Hα
1919 Apr. 1	7.9	<2	—	—	—	much underexposed
May 7	7.6	< 2	—	—	—	much underexposed
May 11	7.5	6	2	28 A	1.7	
June 1	7.6	5	2	25 A	1.7	
July 19	7.3	0	3	30 A	1.7	
Sept 12	7.1	1	2	25 A	1.7	
Nov. 11	7.5	1	?	40 A ±	—	underexposed
Nov. 13	7.5	0	1?	30 A ±	2.0	
1920 Jan. 8	8.3	1	1	60 A ±	1.7	
Apr. 3	8.0	4	1	50 A ±	1.7	Carbon absorption at 6191 A Spectrum 1.5 times as strong at Hα as

Table IV Photographic Region

Date	Mag.	$H\beta$	$H\alpha$
1917 Aug. 6	7.6	0	0
1919 Apr. 20	7.6	2	1
Apr. 26	7.7	3	2
May 26	7.6	4	2
June 4	7.6	1	trace
July 26	7.4	1	0
Sept. 2	7.1	?	0
Oct. 31	7.2	0	0
Dec. 29	8.2	0	0

Table V Visual Region

Date	Mag.	Hα	5845A	D (width)	Remarks
1917 Jan. 31	7.4	4	2	11A ±	overexposed
Oct. 20	8.7	5	2	16A	
1919 Sept. 23	9.0	2	?	16A	
Nov. 3	8.0	0?	?	20A	
1920 Jan. 9	7.1	6	?	14A	
Mar. 18	7.0	7	1?	10A	

Table VI Visual Region.

Date	Mag.	Hα	5845A	D (width)	Remarks
1917 July 25	7.2	0	2	9A	
Oct. 31	7.6	1?	0	6A	
1919 May 11	7.0	1	—	7A ±	poor focus.
June 5	7.0	0	2	9A	
July 19 ~~Sept. 12~~	7.1	1?	1	9A	
Sept 12	7.0	2	?	9A	
1920 Jan. 11	6.9	0	1	9A	
1920 Jan. 9	7.2	2	2	9A	
Mar. 29	7.0	3	2	9A	

Table VII Visual Region

Date	Mag.	Hα	Remarks
1919 Sept. 16	7.6	0?	Star approaching maximum at this d
Nov. 11	7.2	1	slightly underexposed.
1920 Jan. 9	7.2	1	
Mar. 18	7.4	2	

Date	Mag.	Hα	
1919 Aug. 6	8.0	1	
Sept. 12	7.1	2	
Nov. 3	7.1	2.	
1920 Jan. 9	6.5 ±	0	
Mar. 18	7.8	0	

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